APPENDIX I: U.S. EPA Vintaging Model Framework

I.1 Vintaging Model Overview

The Vintaging Model estimates emissions from six industrial sectors: refrigeration and air-conditioning, foams, aerosols, solvents, fire extinguishing, and sterilization. Within these sectors, over 40 independently modeled end-uses exist. The model requires information on the market growth for each of the end-uses, as well as a history of the market transition from ozone depleting substances (ODS) to alternatives. As ODS are phased out, a percentage of the market share originally filled by the ODS is allocated to each of its substitutes.

The model, named for its method of tracking the emissions of annual "vintages" of new equipment that enter into service, is a "bottom-up" model. It models the consumption of chemicals based on estimates of the quantity of equipment or products sold, serviced, and retired each year, and the amount of the chemical required to manufacture and/or maintain the equipment. The Vintaging Model makes use of this market information to build an inventory of the in-use stocks of the equipment in each of the end-uses. Emissions are estimated by applying annual leak rates, service emission rates, and disposal emission rates to each population of equipment. By aggregating the emission and consumption output from the different end-uses, the model produces estimates of total annual use and emissions of each chemical. For the purpose of projecting the use and emissions of chemicals into the future, the available information about probable evolutions of the end-use market is incorporated into the model.

The following sections discuss the forms of the emission estimating equations used in the Vintaging Model for each broad end-use category. These equations are applied separately for each chemical used within each of approximately 40 different end-uses. In the majority of these end-uses, more than one ODS substitute chemical is used.

In general, the modeled emissions are a function of the amount of chemical consumed in each end-use market. Estimates of the consumption of ODS alternatives can be inferred by extrapolating forward in time from the amount of regulated ODS used in the early 1990s. Using data gleaned from a variety of sources, assessments are made regarding which alternatives will likely be used, and what fraction of the ODS market in each end-use will be captured by that alternative. By combining this information with estimates of the total end-use market growth, a consumption value is estimated for each chemical used within each end-use.

I.2 Emissions Equations

I.2.1 Refrigeration and Air-Conditioning

For refrigeration and air conditioning products, emission calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses, and disposal emissions, which occur at the time of discard. Equation 1 calculates the lifetime emissions from leakage and service, and Equation 2 calculates the emissions resulting from disposal of the equipment. These lifetime emissions and disposal emissions are added to calculate the total emissions from refrigeration and air-conditioning (Equation 3). As new technologies replace older ones, it is generally assumed that there are improvements in their leak, service, and disposal emission rates.

Lifetime emissions from any piece of equipment include both the amount of chemical leaked during equipment operation and during service recharges. Emissions from leakage and servicing can be expressed as follows:

$$Es_j = (l_a + l_s) \_ \_\_ Qc_{j-i+1} \quad for\ i=1\_k \qquad \text{Eq. 1}$$

Where:

Es_j = *Emissions from Equipment Serviced.* Emissions in year j from normal leakage and servicing (recharging) of equipment.

l_a = *Annual Leak Rate.* Average annual leak rate during normal equipment operation (expressed as a percentage of total chemical charge).

l_s = *Service Leak Rate.* Average leakage during equipment servicing (expressed as a percentage of total chemical charge).

Qc_j = *Quantity of Chemical in New Equipment.* Total amount of a specific chemical used to charge new equipment in a given year, j, by weight.

k = *Lifetime.* The average lifetime of the equipment.

The disposal emission equations assume that a certain percentage of the chemical charge will be emitted to the atmosphere when that vintage is discarded. Disposal emissions are thus a function of the quantity of chemical contained in the retiring equipment fleet and the proportion of chemical released at disposal:

$$Ed_j = Qc_{j-k+1} \_ [1 - (rm \_ rc)] \qquad \text{Eq. 2}$$

Where:

Ed_j = *Emissions from Equipment Disposed.* Emissions in year j from the disposal of equipment.

Qc_j = *Quantity of Chemical in New Equipment.* Total amount of a specific chemical used to charge new equipment in a given year, j, by weight.

rm = *Chemical Remaining.* Amount of chemical remaining in equipment at the time of disposal (expressed as a percentage of total chemical charge)

rc = *Chemical Recovery Rate.* Amount of chemical that is recovered just prior to disposal (expressed as a percentage of chemical remaining at disposal *(rm)*)

k = *Lifetime.* The average lifetime of the equipment.

$$E_j = Es_j + Ed_j \qquad \text{Eq. 3}$$

Where:

E_j = *Total Emissions.* Emissions from refrigeration and air conditioning equipment in year j.

Es_j = *Emissions from Equipment Serviced.* Emissions in year j from normal leakage and servicing (recharging) of equipment.

Ed_j = *Emissions from Equipment Disposed.* Emissions in year j from the disposal of equipment.

I.2.2 Aerosols

All HFCs and PFCs used in aerosols are assumed to be emitted in the year of manufacture. Since there is currently no aerosol recycling, it is assumed that all of the annual production of aerosol propellants is released to the atmosphere. Equation 4 describes the emissions from the aerosols sector.

$$E_j = Qc_j \qquad \text{Eq. 4}$$

Where:

E_j = *Emissions*. Total emissions of a specific chemical in year *j* from use in aerosol products, by weight.

Qc_j = *Quantity of Chemical*. Total quantity of a specific chemical contained in aerosol products sold in year *j*, by weight.

I.2.3 Solvents

Generally, most solvents are assumed to remain in the liquid phase and are not emitted as gas. Thus, emissions are considered "incomplete," and are a fixed percentage of the amount of solvent consumed in a year. The remainder of the consumed solvent is assumed to be reused or disposed without being released to the atmosphere. Equation 5 calculates emissions from solvent applications.

$$E_j = l \_ Qc_j \quad \text{Eq. 5}$$

Where:

E_j = *Emissions*. Total emissions of a specific chemical in year *j* from use in solvent applications, by weight.

l = *Percent Leakage*. The percentage of the total chemical that is leaked to the atmosphere.

Qc_j = *Quantity of Chemical*. Total quantity of a specific chemical sold for use in solvent applications in the year j, by weight.

I.2.4 Fire Extinguishing

Total emissions from fire extinguishing are assumed, in aggregate, to equal a percentage of the total quantity of chemical in operation at a given time. For modeling purposes, it is assumed that fire extinguishing equipment leaks at a constant rate for an average equipment lifetime. This percentage varies for streaming (Equation 6) and flooding (Equation 7) equipment.

Streaming Equipment

$$E_j = l \_ \_ Qc_{j-i+1} \quad for\ i=1\_k \quad \text{Eq. 6}$$

Where:

E_j = *Emissions*. Total emissions of a specific chemical in year *j* for streaming fire extinguishing equipment, by weight.

l = *Percent Leakage*. The percentage of the total chemical in operation that is leaked to the atmosphere.

Qc_j = *Quantity of Chemical.* Total amount of a specific chemical used in new streaming fire extinguishing equipment in a given year, *j*, by weight.

k = *Lifetime.* The average lifetime of the equipment.

Flooding Equipment

$$E_j = l \_ \_ Qc_{j-i+1} \quad for\ i=1\_k \quad \text{Eq. 7}$$

Where:

E_j = *Emissions*. Total emissions of a specific chemical in year j for streaming fire extinguishing equipment, by weight.

l = *Percent Leakage*. The percentage of the total chemical in operation that is leaked to the atmosphere.

Qc_j = *Quantity of Chemical.* Total amount of a specific chemical used in new streaming fire extinguishing equipment in a given year, j, by weight.

k = *Lifetime.* The average lifetime of the equipment.

I.2.5 Foam Blowing

Foams are given emission profiles depending on the foam type (open cell or closed cell). Open cell foams are assumed to be 100 percent emissive in the year of manufacture. Closed cell foams are assumed to emit a portion of their total HFC or PFC content upon manufacture, a portion at a constant rate over the lifetime of the foam, and a portion at disposal.

Open-Cell Foam

$$E_j = Qc_j \qquad \text{Eq. 8}$$

Where:

E_j = *Emissions*. Total emissions of a specific chemical in year j used for open-cell foam blowing, by weight.

Qc_j = *Quantity of Chemical.* Total amount of a specific chemical used for open-cell foam blowing in year j, by weight.

Closed-Cell Foam

$$E_j = \_\ (ef_i \_ Qc_{j-i+1}) \quad \textit{for } i=1\_k \qquad \text{Eq. 9}$$

Where:

E_j = *Emissions*. Total emissions of a specific chemical in year j for closed-cell foam blowing, by weight.

ef_i = *Emission Factor.* Percent of foam's original charge emitted in each year (1 _k). This emission factor is generally variable, including a rate for manufacturing emissions (occurs in the first year of foam life), annual emissions (every year throughout the foam lifetime), and disposal emissions (occurs during the final year of foam life).

Qc_j = *Quantity of Chemical.* Total amount of a specific chemical used in closed-cell foams in year j.

k = *Lifetime*. Average lifetime of foam product.

I.2.6 Sterilization

For sterilization applications, all chemicals that are used in the equipment in any given year are assumed to be emitted in that year, as shown in Equation 10.

$$E_j = Qc_j \qquad \text{Eq. 10}$$

Where:

E_j = *Emissions*. Total emissions of a specific chemical in year *j* from use in sterilization equipment, by weight.

Qc_j = *Quantity of Chemical.* Total quantity of a specific chemical used in sterilization equipment in year *j*, by weight.

I.3 Model Output

By repeating these calculations from the years 1985-2030, the Vintaging Model creates annual profiles of use and emissions for ODS and ODS substitutes. The results can be shown for each year in two ways: 1) on a chemical-by-chemical basis, summed across the end-uses, or 2) on an end-use basis. Values for use and emissions are calculated both in metric tons and in million metric tons of carbon dioxide equivalents ($MMTCO_2$). The conversion of metric tons of chemical to $MMTCO_2$ is accomplished through a linear scaling of tonnage by the global warming potential (GWP) of each chemical. The GWP values that are used in the model correspond to those published in the IPCC Second Assessment Report.